FIBER CREEP AND RUPTURE MODELS FOR DESIGN OF ADVANCED HIGH-TEMPERATURE SIC-BASED CERAMIC MATRIX COMPOSITES

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With the objective of seeking improved temperature capability for SiC/SiC CMC components in future aerospace engines, this presentation discusses the results of recent studies at NASA aimed at understanding the multiple microstructural factors controlling the high-temperature creep strain and rupture strength behavior of current near-stoichiometric SiC fibers and their composites. These polycrystalline fibers include polymer-derived Hi-Nicalon-S, polymer-derived and sintered Tyranno SA3 and Sylramic-iBN, and CVD-derived Ultra SCS fiber. Based on experimental data generated at NASA and within the literature, empirical models have been developed that describe the axial creep strain in the primary and secondary stages for these single fibers as a function of time, temperature, and stress as well as their key microstructural variables. Of fundamental and practical importance is that all of the polymer-derived fibers with nearly equiaxed grains display a long-time steady state creep strain that grows with a stress dependence to the third power and with an inverse linear dependence on average grain size; whereas the CVD-derived Ultra SCS fiber with non-equiaxed grains displays only a primary stage with a time dependence to the 1/3 power and a linear stress dependence. Included in these models are empirically derived creep parameters for each fiber type and their creep activation energy, which for all but the SA3 fiber corresponds to the diffusion energy for carbon in SiC. It is shown that these models also predict the high-temperature axial creep of tows within SiC/SiC CMC (1) when the matrix is either cracked or carries little load due to poor creep resistance and (2) when the fiber tows are not bent or woven, but are axially aligned along the CMC stress direction.

The fundamental and practical implications of the creep models are discussed, such as the current problems with the small grain size in the Hi-Nicalon-S fiber, the non-uniform grain size distribution in the sintered fibers, and the aluminum elements and free silicon in the SA3 and Ultra SCS fibers, respectively. Thus these models also show where significant microstructural improvements are still available in current fibers that will allow the achievement of an “Advanced” SiC fiber with significant improvement in temperature capability. It also discussed how with these improvements, the advanced SiC fiber will display other important properties required for improved CMC thermo-structural performance, such as enhanced surface roughness for increased fiber-matrix interfacial strength, enhanced thermal conductivity for CMC thermal stress reduction, and enhanced fracture toughness for better flaw tolerance.

For the rupture strength models, it is assumed that intrinsic fiber rupture life at high temperatures is controlled by creep-generated cavitation flaws that grow between grains as they slide past each other. Then using Griffith’s theory for fracture strength and assuming the critical flaw size is directly proportional to the fiber steady-state creep strain for the polymer-derived fibers and to the primary creep strain for the CVD fiber, functional models for the fiber rupture strengths are developed with all the service and microstructural variables contained in the creep strain models. When the rupture models are compared with limited fiber rupture strength versus time data at a given temperature, excellent agreement is obtained allowing empirical rupture parameters to be derived for each fiber type. The models also closely predict the rupture life of CMC reinforced by these fibers, again as long as the matrix carries little load and the fiber tows are aligned in the CMC stress direction. Thus with the fiber creep strain and rupture strength models, one can now predict CMC maximum use temperature for each fiber type as well as for the advanced SiC fiber, either if total creep strain is a service limitation, or if avoiding fiber rupture is the limitation. Finally, it is briefly shown that these creep and rupture models are also applicable to oxide fibers such as the Nextel 610 fiber, which, like the polymer-derived near-stoichiometric SiC fibers, displays a steady state creep strain with a stress dependence to the third power.

This presentation concludes with suggested microstructural and process approaches for each SiC fiber type and their CMC architectures and matrices in order to improve the ability to achieve advanced SiC/SiC CMC with improved intrinsic temperature capability.